Methyl bromide alternatives

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Inside This Issue

Plants: Guilty of Producing and Releasing Methyl Bromide?

It is generally understood that anything which destroys stratospheric ozone molecules thins the ozone layer, allowing potentially harmful ultraviolet light to reach the earth. It is also known that methyl bromide, the fumigant now widely used in agriculture throughout the world, has been declared an ozone depletor. Scientists have even estimated the amount of methyl bromide emissions that can be attributed to agricultural use of the chemical.

What is not known is how much of the total amount of methyl bromide emitted into the atmosphere comes from plants. Jay Gan, a soil chemist with USDA's Agricultural Research Service, has just completed a study that sheds some light on this uncertainty. He is with the U.S. Salinity Laboratory, an ARS research facility in Riverside, California.

In collaboration with J. Sims at the University of California-Riverside, Gan and S.R. Yates found that *Brassica* plants take bromide from the soil, convert it to methyl bromide, and then release it into the atmosphere. *Brassica* species include both wild and domestic plants such as mustard, kale, cabbage, broccoli, rapeseed, turnips, and radishes.

"We selected *Brassica* because Canadian scientists have proven that leaf parts of this species produce methyl bromide," Gan reports. "But whole plants had not been tested before to see if they produce and release methyl bromide. There is a missing source of atmospheric methyl bromide. Unlike completely manmade ozone depletors, methyl bromide comes from manmade and natural sources. We know that methyl bromide is put into the air by the oceans, biomass burning, emissions from leaded gasolines, and agricultural fumigation. But these sources don't account for the total amount of methyl bromide emitted into the atmosphere. Maybe green plants could be responsible for a significant amount of the missing source."

Gan and colleagues first measured methyl bromide emitted from plants grown in soil containing different levels of bromide. "It is known that most soils contain bromide, but we added differing amounts to soil and transplanted seedlings in the greenhouse," he says. "We used broccoli, cabbage,

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

Address technical questions to Kenneth W. Vick, USDA, ARS, National Program Staff, Room 4–2216, 5601 Sunnyside Avenue, Beltsville, MD 20705–5139. Phone (301) 504–5321, fax (301) 504–5987.

Address suggestions and requests to be added to the mailing list to Doris Stanley Lowe, USDA, ARS, Information Staff, 128 Smallwood Village Center, Waldorf, MD 20602. Phone (301) 893–6727, fax (301) 705–9834.

mustard, Chinese cabbage, and pak-choi, all cultivated *Brassica* species. We also planted alyssum and wild mustard, both wild species."

After 2 to 6 weeks, they put the plants in a closed glass container for 24 hours to let the methyl bromide accumulate to a measurable amount. Gan measured the methyl bromide by taking samples of the air from the jars and analyzing them using gas chromatography.

"We found that the initial rates of methyl bromide produced correlated to the amounts of bromide we added to the soil," Gan reports. He says that the average amount of bromide in soil is about 1 ppm (part per million), depending on where the soil is sampled. "As you get closer to the ocean, soils contain more bromide; farther inland, they contain less."

In their second experiment, Gan and his collegues used field-grown *Brassica* plants. "We used broccoli, rapeseed, cabbage, and wild mustard plants. We took the plants from the field with soil still attached to the roots. Again, we placed the plants in sealed containers in the lab to capture methyl bromide emissions," Gan explains.

Although the bromide level was less than 0.6 ppm in any of the soils tested, significantly, methyl bromide emissions were still measured. Thus, under natural conditions, *Brassica* plants were able to extract bromide from the soil, convert it to methyl bromide, and release it.

Since they knew that the soil or the plants themselves could degrade the methyl bromide produced in the 24 hours the plants were in the jars, Gan and colleagues did separate degradation experiments to derive the actual methyl bromide production rates.

After they measured methyl bromide production, they separately measured the bromide content in the plants and soil to determine the plant uptake of bromide from the soil.

"We recovered 95 to100 percent of the spiked bromide from plant tissues," Gan says. Using the rates at which methyl bromide is produced by cabbage and rapeseed—for which the global biomass is known—and a linear relationship between this rate and soil bromide, Gan estimates that, globally, rapeseed alone could produce 6.6 million kilograms of methyl bromide each year. And cabbage, 0.4 million kilograms, more or less.

The preliminary study also showed that radishes and turnips can produce methyl bromide. "We found that the Brassicaceae family as a whole is capable of producing methyl bromide," Gan says.

Worldwide, the Brassicaceae family is an important part of the terrestrial plant biomass, made up of vegetables, oil crops, pastures, ornamental crops, weeds, and wild species.

"We think it is possible that the amount of methyl bromide produced by this family of plants may be substantial," Gan says. "And although these were the only plants in our study, there are probably many other terrestrial plants out there producing methyl bromide."

Since methyl bromide has manmade and natural origins, Gan thinks it's critical to understand the sources. We may be able to control the manmade sources but are not likely able to do much with the natural ones. Right now, he points out, there are important facts that aren't being considered in estimating the amount of methyl bromide in the atmosphere. First, we haven't considered the fact that soil contains a certain amount of bromide and that nonextractable bromine can be released as bromide. Second, the earth's crust of soil is a large bromide reservoir.

"Our research suggests that land plants may be a link between soil bromide and stratospheric methyl bromide," Gan says. "Our findings also agree with the ratio of 1.2 to 1.4 northern to southern hemispheric ratio of atmospheric methyl bromide. Because the northern hemisphere has a greater landmass than the southern, it would follow that it also has a greater capacity for plants to produce methyl bromide."

"We think more study is needed on the terrestrial ecosystem as it relates to depleting the ozone layer," Gan says.

Jordanian Farmers Adopt Methyl Bromide Alternatives

In the Jordan Valley, a deep rift valley where the Jordan River flows, temperatures can reach 110°F in the summer months. But Jordanian farmers can use this to their advantage, according to Volkmar Hasse. He is with the Deutsche Gesellschaft fuer Technische Zusammenarbeit, which gives technical help to developing countries on behalf of the German Federal Ministry for

Economic Cooperation and Development.

Through a bilateral Jordanian-German technical cooperation project, Hasse and a team of colleagues are introducing integrated pest management (IPM) to Jordanian farmers. He is also working on a project—funded by the German government through the Multilateral Fund—to help these farmers adopt methyl bromide alternatives.

"Our cooperators include pioneer farmers, several government institutions, nongovernment organizations, private companies, and local universities. Since 1995, the IPM project has helped us develop methods to wean Jordanian farmers from misusing pesticides in their fields. We're now trying to use these methods to convince methyl bromide users to convert to cheaper, more environmentally friendly alternatives," Hasse reports.

The Jordan Valley lends itself well to the use of soil solarization to eliminate soilborne pathogens, Hasse contends. Soil solarization is the technology whereby a grower covers the soil with sheets of plastic to trap the sun's heat and warm the moistened soil in order to control soilborne pathogens. Since 1981, Walid Abu Gharbieh and colleagues from the University of Jordan have been researching soil solarization as a preplant treatment to control soilborne pathogens of greenhouse and open field vegetables in the Jordan Valley. "Their efforts didn't stop at academic research," Hasse points out. "Gradually over the years, hundreds of farmers adopted solarization after seeing the successful trials."

Was it a hard task to convince growers to switch from indiscriminate use of pesticides to IPM? "Once farmers adopt a technology that meets their needs economically and effectively, it's hard to get them to change," Hasse answers. "And like other farmers, Jordanian farmers have been relying on chemical pesticides for years. The pesticides are easy to apply, are financially acceptable, and ensure them against crop losses, the growers feel. But, just as the market is driven by price, so are farmers. Farmers are concerned with costs. If a new technology promises to be cheaper and as good as what they're using, farmers are prepared to overcome their fears and try it."

During 1997, he says, the price for methyl bromide almost doubled because of supply shortages when it was time to prepare the land for planting. Many farmers then turned to the cheaper solarization even though they had only heard about the technology and didn't really understand it.

At regular prices, the cost of applying methyl bromide is about $1,180 per acre ($292 per 1,000 m^2), while the same area could be treated just as effectively with soil solarization for about $567 per acre ($140 per 1,000 m^2).

Also, Hasse continues, research results showed other beneficial effects of soil solarization. "Plants appeared stronger and sometimes gave higher yields in these soils. There were also positive changes in the composition of soil microorganisms, especially at less-than-sterilizing temperatures. For example, beneficial organisms like the fungus *Trichoderma*, seem to be more heat resistant than pathogenic organisms and survive in solarized soil. But methyl bromide literally wipes out everything."

A group of rural women farmers in the Jordanian Valley has been cooperating with the IPM team. Together, they tried soil solarization in a different way. Instead of covering the soil with large sheets of clear plastic, several weeks before the season they laid down the same strips of black plastic mulch that are used for planting. In addition, they added *Trichoderma* under the plastic.

According to Hasse, the soil under the black plastic heats up but less than under clear plastic. The raised temperatures increase the growth of *Trichoderma*, while significantly reducing the growth of pathogenic fungi.

"Based on their positive experience, we did an economic assessment for small farmers. Considering that there was no need for the large sheets of clear plastic and that much less labor was required, the average cost for strip solarization (including the fungus) was reduced to about $162 per acre ($40 per 1,000 m^2)," Hasse says.

Soilborne diseases increased only slightly to about 3 percent where the women used solarization in 1997. This, Hasse says, could be attributed to the very short treatment period of only 3 weeks. No soilborne diseases were observed in 1998 when they extended solarization to 5 weeks.

Growers could relate to these facts, unlike when scientists spoke of preserving the ozone layer, saving the earth for future generations, or even protecting human health.

"When introducing IPM, we proposed our technologies to several well-educated 'pioneer farmers' for trial on small plots on their farms, providing them with technical assistance. This worked quite well because when these farmers later decided to expand the new methods to larger segments of their farms, the technology transfer process was already successfully established," Hasse explains.

But the real challenge, he says, is to bring the adapted technologies to most of the farming population of the country. Hasse and colleagues organized field days to promote contact between the pioneer farmers and the general farming population. This hands-on approach on a working farm helps experienced technical personnel to carefully demonstrate how the new methods work on farmers' own land.

"We use the pioneer farmers as experts to explain the technology to new farmers," Hasse says. "This helps avoid costly mistakes due to a lack of understanding by the new farmers."

Although the media can spread the word about using alternatives to methyl bromide, radio or TV cannot replace the benefits of the personal, hands-on experience, he notes.

Jordanian farmers accepted soil solarization because it was shown to be an economically and ecologically viable technology.

One Jordanian vegetable grower speaks highly of soil solarization. "From my experience, there is no pest in my fields that can't be controlled by solarization. I plant seeds, not seedlings in the solarized soil and get 99-percent emergence without any soilborne disease problems," says Khalil Abu Ghannam. He uses soil solarization to grow tomatoes, cucumbers, strawberries, eggplant, beans, sweet peppers, and onions. Pests and soilborne diseases controlled include *Meloidogyne*, *Fusarium oxysporum*, *Pythium*, *Sclerotinia*, *Verticillium*, white grub, weeds, and *Orobanche*.

Abu Ghannam used the following solarization processes from mid-June to mid-September, the hot off-season in the Jordan Valley:

- Remove the residues from the previous crop.
- Plow deeply.
- Add unfermented manure and rotovate the soil to incorporate the manure.
- Divide the area into plots with low dikes around them.
- Flood the soil with water, 53,500 to 64,000 gal/acre.
- Flood again after 2 weeks, 43,000 to 53,500 gal/acre.
- Plow and rotovate after 10 to12 days to prepare soil for solarization.
- Place drip irrigation lines.
- Cover soil with clear polyethylene plastic (2-percent UV, 100 mcg) and seal the edges tightly with soil.
- Add water at 6,400 gal/acre.
- Add water every 5 days, for 45 to 50 days at 4,300 gal/acre.

Hasse notes that the water is subsidized by the Jordanian government, so farmers don't bear the full financial responsibility.

At noon on Abu Ghannam's farm, the soil temperatures are very warm: at 2 inches depth, 140°F; 6 inches, 136 to 138°F; and 8 inches, 124 to 126°F.

"My yield using soil solarization was not significantly different from what I got when I used methyl bromide to fumigate the soil," Abu Ghannam reports. "Therefore, my profit from using soil solarization is the difference of input costs."

In the Jordan Valley, solarization is primarily used on tomato, cucumber, pepper, and strawberry crops, Hasse says. "We've seen a voluntary increase in the use of solarization. This indicates that Jordanian farmers are prepared and ready to adopt this new technology. Perhaps this will help Jordan accelerate the phaseout of methyl bromide."

Insects Feel the Electricity in Possible MeBr Alternative

Microbursts of high-voltage electricity could provide a new avenue of research for postharvest control of insects on citrus and other fruit, according to Agricultural Research Service and Ohio State University scientists.

Pulsed electric fields (PEF), as such jolts are called, have been recently studied to inactivate microorganisms such as *E. coli* in food. PEF is used on liquids such as apple juice in a cold pasteurization process to avoid the changes in color, flavor, texture, and nutrients that the heat of thermal pasteurization can cause.

Reading a technical report on the subject by Q. Howard Zhang, who is with the Ohio State University Department of Food Science and Technology, gave ARS entomologist Guy J. Hallman the idea of seeing if such pulses could take care of insects inside of fruit without damaging the produce.

"I figured if microsecond bursts of 25,000 volts killed *E. coli*, much lower voltages would disrupt fruit flies because they are much more complex organisms," said Hallman, who is with the ARS Crop Quality and Fruit Insects Research Unit in Weslaco, Texas.

The two scientists found that ten 50-microsecond pulses of 9,000 volts were enough to kill all but three percent of Mexican fruit fly eggs in a small chamber. Of the few eggs that did hatch, none survived to become large larvae. Each pulse was only 1/20,000 of a second long.

Larvae exposed to even smaller, 2,000-volt pulses, while not killed outright, became very sluggish or paralyzed, and began dying a few days later. None of the exposed larvae developed into pupae.

"It is very similar to the effect of irradiation in the sense that, instead of immediately killing an insect, PEF disrupts the insect's ability to mature or reproduce," Hallman explained.

The comparatively low level of electricity and especially the very short durations of the pulses also require only a small total amount of energy and generate very little heat, so treated fruit are not likely to be harmed by the process, Hallman added.

But at this point, Hallman and Zhang have tried the micropulses only on free fly eggs and larvae; they have not tried controlling fruit flies directly in fruit because they lack the necessary equipment. Many additional steps must be taken to prove PEF can completely control fruit flies and that the citrus quality remains the same after treatment.

"We've only opened an interesting door at this point, but it is worth taking a longer look at PEF. We need to see if this is practical on a commercial scale, scientifically and economically," Hallman said.

The problem is no one is building commercial PEF machinery right now. Zhang and Hallman are working with an old PEF generator that had been shelved by the National Aeronautic and Space Administration after it was used to test communications microwave tubes in a Strategic Defense ("Star Wars") Initiative.

ARS is currently seeking an industrial partner to further explore PEF's possibilities. "I'm not ready to be either optimistic or pessimistic about pulsed electric fields as an alternative to methyl bromide for postharvest control of insects like fruit flies on citrus, but it is an idea worth more research," Hallman said.

Perlite and Hydroponics: Possible Substitute for Methyl Bromide?

Worldwide, methyl bromide is used primarily as a soil fumigant to eliminate soilborne pathogens and to control weeds. Since methyl bromide will no longer be available to U.S. growers after 2005, scientists are persistently seeking alternatives to this chemical that has been so widely used for decades.

George J. Hochmuth has been researching the idea of growing crops hydroponically in a soil-less mixture, eliminating the need for methyl bromide. Collaborators include Tim Crocker—who along with Hochmuth, is an extension specialist with the University of Florida's Horticultural Sciences Department—and Bob Hochmuth, with the university's Suwannee Valley Research and Education Center.

"On research plots at the University of Florida, we've been growing muskmelons in walk-in and low tunnels using perlite in a soil-less culture system," George Hochmuth reports. "Our data show that this is a possible alternative to fumigating the soil with methyl bromide. We've also successfully grown strawberries in an outdoor hydroponic system using perlite bags."

Each year, about $4 billion worth of horticultural crops are produced worldwide with soil-less cultures. According to Hochmuth, although these technologies are widely used around the world, they aren't used as extensively in the United States. This is primarily because U.S. land available for agriculture is becoming more and more expensive. In 1988, U.S. growers produced about $32 million worth of crops with soil-less mixtures, while in 1992, growers in Holland alone accounted for about $1.6 billion. Today, the estimated value of Florida's greenhouse vegetable industry is $20 million. However, with the impending ban on methyl bromide, U.S. growers need viable options to stay in the business of producing the nation's winter supply of fresh fruits and vegetables.

"The impending loss of methyl bromide will almost certainly lead to reduced yields under soil-based fruit and vegetable production in environments such as we have in Florida where soil pathogens, if left uncontrolled, can severely

affect crop growth," Hochmuth says. "The good news is that in our research experiments, we got higher yields in tunnels planted with perlite than in those planted with soil."

Perlite is a unique volcanic mineral that has been used for years to amend professional potting soils made from peat moss. It retains and holds substantial amounts of water, which can be released as needed. The research was collaborative with the Schundler Company, Metuchen, New Jersey—a member of the Perlite Institute, New York City, which funded the research along with Airlite Products, Vero Beach, Florida.

Strawberries

Produced on 6,000 acres and valued at over $100 million each year, strawberries are important to Florida growers. Essentially all Florida strawberries are grown using plastic mulch culture in fields, with little chance for crop rotation. Each year, the soil must be fumigated with methyl bromide to control diseases, weeds, and nematodes before new mulch is applied.

"We placed perlite and a peat mix in layflat bags about 3 feet long and 10 inches in diameter. We placed the bags end to end on a level area of soil covered with black plastic," Hochmuth says. After three fertilizer treatments, Hochmuth and colleagues planted six plug plants per bag and managed disease, insects, and mites by integrated pest management. On a per-acre basis, perlite bags allowed twice the numbers of plants that could be accommodated by typical field culture with plastic mulch.

"We harvested an average of just under a pound per plant, not significantly different from the yield achieved with methyl bromide fumigation in soil," he reports. "Considering that on a per-plant basis we achieved the same yields, we actually produced twice the yield of the field system since we had twice the number of plants, per acre, in the perlite bags." However, Hochmuth says that further refinement of the amount and timing of the controlled-release fertilizer applications is needed before large-scale adoption of this technique.

Muskmelons

Using perlite, Hochmuth and colleagues planted Galia muskmelons in walk-in tunnels and low tunnels during the winter/spring and fall/winter growing seasons in 1997 and in the winter/spring season in 1998. Colleagues include Eric A. Waldo, Daniel J. Cantliffe, and Steven A. Sargent, all with the University of Florida at Gainesville.

Walk-in tunnels are quonset-style structures covered with a single layer of polyethylene film, heated and cooled passively without powered equipment; and low tunnels are simply row covers.

"In half of the rows under both types of tunnels, we used perlite for our growth medium. For the other half of the plants, we used raised beds of soil, polyethylene mulch, and drip irrigation," Hochmuth explains. They also placed thermal tubes in half of the walk-in tunnels. These tubes, which are about 12 inches in diameter and hold water, act as solar collectors during the day and release the energy as heat during the night.

According to Hochmuth, the tunnels and thermal tubes protect crops from cold temperatures, which can extend the growing season. "This gives the grower the advantage of premium, off-season prices."

Soil-less Culture

Using soil-less mixtures such as perlite, Hochmuth says, eliminates the need for methyl bromide: since there is no soil, there are no soilborne pathogens or weeds. "In addition, as issues such as land availability and water use become more important, soil-less culture may prove to be an acceptable alternative to traditional soil-based crop production," he says.

Hydroponics offers many benefits. For example, nutrient runoff from growing crops can be captured and reused by growers as fertilizer for pastures or other crops. This can prevent the problem of excess fertilizer leaching into groundwater from the soil.

And as land prices increase, growers need to optimize use of their land. Soil-less mixtures maximize crop yield per acre.

With soil-less mixtures, plants get water and nutrients through a nutrient solution and are physically supported by a soil substitute such as rockwool or perlite.

Most soil-less mixtures have good aeration and drainage capacities. "Perlite is also sterile, has a neutral pH, and is readily available, nontoxic, safe to use, and relatively inexpensive," says Bruce Schundler, president of the Schundler Company. "Also, it can be used in the greenhouse or in outdoor plantings. It's ideal for water conservation and expands

from four to 20 times its original volume when heated quickly. Plants grown in perlite take up water as needed; they don't suffer from too much or too little water."

This is because the surface of a particle of perlite contains tiny cavities that hold moisture and nutrients which are available to plant roots. The particle's shape lends itself to numerous air passages, which provide optimum aeration and drainage. Since it is sterile, perlite is free of diseases, seeds, and insects.

"Perlite's ability to cling to plant roots and root hairs helps reduce transplant shock and production time. It is being used for propagation and seed cultivation, plug production and transplants, interiorscape and planter growing, composting, hydroponic cultures, turf and lawns, and placement around shrubs, trees, and landscaping," Schundler reports.

In addition to aiding drainage, perlite eliminates soil crusting in heavy clay soils. Also, plant roots more easily penetrate the perlite growing media.

Tomato plants grown hydroponically in perlite have produced average yields 7 percent higher than tomatoes grown in other soil-less mediums. In Holland and, to a lesser degree in the United States, commercial cut flowers, strawberries, and orchids are being grown in 100 percent hydroponic perlite, Schundler says.

"A grower who wants to use perlite to grow crops should follow a few basic guidelines," Schundler iterates. "The first criterion is to carefully plan the nutrient solution system and the second is to frequently monitor irrigation, temperature, and nutrient levels throughout the season, then adjust the systems as necessary."

Growers should develop backup systems and procedures to ensure an adequate water supply to administer the nutrient solution system. "Careful consideration should be given in selecting the optimum nutrient program appropriate for the particular crop being grown" Schundler says.

Walk-in Tunnels

What exactly is a walk-in tunnel? A portable, walk-in, greenhouse-like structure without a permanent electrically powered heating or ventilation system, covered with one layer of plastic, and sited on field soil, says Hochmuth. "These tunnels can't protect crops from temperatures to the same degree that heat-equipped greenhouses can. But, they cost a lot less to build and operate, and they're effective."

Walk-in tunnels have been used extensively throughout the Middle East, Asia, and southern Europe to grow vegetables. And some tomato growers in the northeastern United States have used this practice since about 1992.

"Laying clear polyethylene tubes filled with water along crop rows has effectively moderated cool temperatures and led to increased early yields of peppers, compared to black polyethylene tubing," Hochmuth reports. "We add chlorine bleach to keep algae from growing in the water."

To deter insects, Hochmuth's team used an insect screen that covered the entire side of the tunnel from the ground to about 70 inches high and was buried in the ground to provide additional anchoring for the tunnel structure.

Understanding the dynamics of humidity and the temperature of air and growing media in the tunnels is of utmost importance to the success of the project, Hochmuth says. The effect of outside temperatures on inside temperature and humidity levels is also important.

"We had to reduce high humidity levels in the tunnels because fungal and bacterial diseases as well as some insect pests thrive in this environment. We simply lowered the sides of the tunnels when night temperatures were predicted to be below 50°F and raised the sides on cloudy days when outside temperatures were above 65°F. On sunny days, we raised the sides when outside temperatures were above 50°F. For our row-cover tunnel crops, we'd apply floating row covers over crops when outside temperatures were expected to drop to around 36°F."

This regime was used for muskmelons; strawberries will thrive under much cooler conditions, he says.

"Based on our research results with winter production of Galia muskmelons and with strawberries, we feel that using protective structures and soil-less mixtures is a viable option for growers faced with the loss of methyl bromide," Hochmuth says. "At the University of Florida, we're using this system as well as soil-based cultivation systems to grow a variety of crops without methyl bromide."

IR–4 Addresses Methyl Bromide Alternatives for Growers of Minor Crops

Growers of certain minor crops will face additional challenges to economic survival once methyl bromide is banned in the United States in 2005. Products available to these growers to protect their crops are already limited because more attention is being given to products that will protect major crops. This is because pesticide manufacturers sell more products for major crops than for minor crops. Minor crops are those for which the volume of pesticide needed is not enough to justify a manufacturer's cost to meet the regulatory requirements for registration by the Environmental Protection Agency (EPA).

But growers of these crops—which include vegetables, fruits, nuts, herbs, ornamentals, and nursery plants—have an advocate: IR–4. IR–4, the Interregional Research Project No. 4, is a joint program of the U.S. Department of Agriculture and the state agricultural experiment stations set up in 1963 to address the needs of minor-crop producers in the United States.

"One of our current primary goals is to help develop new products that can serve as methyl bromide alternatives for strawberries and tomatoes. These crops account for about 80 percent of the preplant use of this chemical in the United States," says Jack Norton, IR–4 special projects manager. "We've always helped growers of minor crops produce a plentiful supply of the high-quality fruits and vegetables that U.S. consumers have come to expect and at reasonable prices. And we've just formed a new technology team to ensure that concerns of minor-crop growers are considered during the priority-setting process used by companies in developing these products."

Representatives from USDA's Agricultural Research Service (ARS), land grant universities, private research organizations, agrichemicals industry, EPA, and crop producers participate in the IR–4 program. IR–4 is headquartered at the New Jersey Agricultural Experiment Station in New Brunswick. Because of this collaboration, IR–4 is composed of a unique, highly trained group of professionals who have the interests of minor-crop growers at heart.

"We're looking at new products that will control soilborne diseases, nematodes, and weeds, which minor-crop growers now control with methyl bromide. Through field trials, we expect to determine optimum use rates, use patterns, methods of application, and crop safety of new products that have shown potential as methyl bromide alternatives. Also, we plan to demonstrate the efficacy of some products already registered for use as alternatives to methyl bromide and to use them as standards for new products," Norton reports.

"Weed control—both for annuals and for perennials like yellow and purple nutsedge—is a critical part of the IR–4 methyl bromide

Interregional Research Project No. 4 (IR–4)

IR–4 is made up of representatives from state agricultural experiment stations; U.S. Department of Agriculture's Agricultural Research Service and the Cooperative State Research, Education, & Extension Service; Environmental Protection Agency; and the agrichemicals industry. It is a grassroots organization, which allows pest management needs to be initiated by individual growers, grower groups, nurserymen, agricultural scientists, and extension personnel. IR–4 provides a network of state and federal liaison representatives throughout the United States, including the District of Columbia, Puerto Rico, Guam, and the Virgin Islands to help growers of minor crops. For more information, contact the headquarters office of IR–4 at the following address:

Jerry Baron, Assistant to the Director
Center for Minor Crop Pest Management
Technology Centre of New Jersey
Rutgers, The State University of New Jersey,
681 U.S. Highway #1 South
North Brunswick, NJ 08902–3390
Phone: (732) 932–9575, ext. 605; fax: (732) 932–8481
Email: jbaron@aesop.rutgers.edu
Website: http:/www.aesop.rutgers.edu/~ir4

alternatives research program," he continues. "One concern is that most of the products available as methyl bromide alternatives on strawberries and tomatoes don't adequately control weeds."

The new team is bolstering the development of halosulfuron for weed control in tomatoes and expects to run crop safety tests this year. Norton says that IR–4 is also working with EPA to register metolachlor and pendimethalin for controlling weeds in tomatoes. Although these herbicides can be used on other crops, they're not yet approved for use on tomatoes. "We're also working with a couple of companies to register glyphosate to control weeds in 'Roundup Ready' strawberries," he reports. "If plant material is available, we'll probably begin field tests in the fall of 2000."

The companies, Monsanto of St. Louis, Missouri, and DNA Plant Technologies, Oakland, California, are also collaborating with IR–4 on developing transgenic strawberry plants that will tolerate glyphosate. Plans call for this approach to be combined with standard programs such as metam sodium and Telone.

New products planned for evaluation by IR–4 include Plantpro 45, a complex form of iodine from Ajay, North America; Dazitol, a natural product from Champon Natural Products, and Enzone (sodium tetrathiocarbonate) from Entek Corporation.

"Our research will be funded by participating companies," Norton notes. "And the research will be done and field tests run in the U.S. production areas where most of the strawberries and tomatoes are grown: California and Florida. We're seeking input from ARS and land grant universities."

The programs are expected to be ongoing until 2005, with program redirections being made as new products, technologies, and concepts become available.

Through contacts with agricultural chemical companies, IR–4's new technology team becomes aware much earlier of products and combinations of products that may substitute for methyl bromide. Fludioxonil is a good example of this, Norton says.

"Fludioxonil controls root rot/vine decline of cucurbits like cucumbers, squash, cantaloupes, and watermelons in Texas, Arizona, and California. Novartis produces this product, and IR–4 can give high priority to developing it as a potential methyl bromide substitute," he points out.

Norton says that in addition to chemicals, IR–4 will incorporate cultural practices into its methyl bromide alternatives program. "We've been talking with Speedling, Inc., a company with nurseries in Florida, Maine, and California, about using plug versus bare-root strawberry plants. Plug plants usually establish more efficiently than bare-rooted plants. This would be a clear advantage if alternative fumigants are only marginally effective against certain soilborne diseases or nematode species."

Technical Reports

Assessing Ammonium Lignosulfonate as a Soil Amendment To Control Soilborne Diseases

George Lazarovits, Nader Soltani, and Kenneth Conn, Southern Crop Protection and Food Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford Street, London, Ontario, Canada N5V 4T3 (Lazarovitsg@em.agr.ca)

Ammonium lignosulfonate (ALS), a waste byproduct of the pulp and paper industry with a high nitrogen and carbon content, can be used as a soil amendment to increase the organic matter of soils. The addition of organic materials to soils invariably alters soil microbiology, and those organisms that can utilize the energy of the organic product increase in population. Under ideal conditions, microorganisms could be increased that are either directly beneficial to plant growth or are indirectly beneficial, in that they displace detrimental organisms such as plant pathogens. Therefore, microbial populations conducive to plant health can be manipulated by "feeding" them the right substrate. We have been studying the effects of ALS on soil microbial populations and as a control of Verticillium wilt and potato scab.

Verticillium wilt is caused by the fungus *Verticillium dahliae* and potato scab is caused by bacteria belonging to the genus *Streptomyces*. Earlier studies by our lab have shown that both these pathogens are excellent models for studying the effects of soil amendments to control diseases caused by soilborne pathogens.

We set up field plots in April 1998 at a farm near Delhi, Ontario, where the potato crop in the previous year had a severe scab problem. Treatments included a control and two concentrations of ALS (0.5 and 1.0 percent v/w). Plots, 4 × 7.6 m, were set up in a completely randomized block design with three replications for each treatment. ALS was watered into each plot and rototilled to a depth of 15 cm. Weed emergence in the plots was determined four weeks later. We planted potato tubers (cv. Yukon Gold) four weeks after treatment application. From four rows of potatoes, we collected data from only the two middle rows.

All plots received the same recommended fertilizer. The effects of ALS on soil pH and microbial populations were determined. We attached bags containing *V. dahliae* resting structures (microsclerotia; MS) to plastic stakes and buried them in soil (2 bags/plot) immediately after applicating amendments. After four weeks, we removed the bags, plated onto a semi-selective medium and determined the percent germination of MS, and determined the Verticillium wilt incidence in mid-August. In the fall, we harvested tubers from the middle two rows of each plot and determined the yield and scab severity.

Results from our experiments showed that incorporating ALS into soil increased populations of most microorganisms. Populations gradually returned to control levels by the end of season except for the fungi, which remained higher than the control. The weed population was more than 6-fold lower in 0.5 percent ALS-treated plots than control plots. Weed numbers in 1.0 percent ALS-treated plots were even further suppressed. ALS caused a decrease in soil pH at both concentrations used by about 0.5–1 unit below untreated soils. The viability of *V. dahliae* microsclerotia was reduced by 40 percent with ALS treatment and the Verticillium wilt incidence in the crop, by more than 50 percent. Populations of pathogenic scab bacteria in soil were reduced by 10–100-fold after ALS application and the incidence of potato scab was reduced in all ALS treated plots. The scab severity in 0.5 percent ALS-treated plots was reduced by 6-fold compared to control plots.

We also observed a marked reduction in populations of plant pathogenic nematodes. Total yield was slightly lower in ALS-treated plots compared to the control. However, most of the tubers from the control plots were not marketable as they were severely infected with scab. In contrast, tubers from ALS-treated plots had less than 5 percent scab on their surface and most were of marketable grade. Marketable yield in 0.5 percent ALS-treated plots was more than 20-fold greater than the control plots.

Adding ALS to soil reduced populations of important fungal and bacterial soilborne pathogens, while increasing the overall microbial population by 10–100-fold. The net benefit of the changes in populations of all soil microorganisms is not yet clear, but is likely to be shown in subsequent crops. Indications are that ALS could become a component for plant disease control and an alternative to fumigants for the control of soilborne plant pathogens. In addition, ALS contributes to soil fertility and to soil structure. At the higher concentrations used, however, ALS was phytotoxic to potatoes. This phytotoxicity was non existent or transitory at rates below 0.5 percent and the plants recovered and caught up to the plants in untreated soil. Current studies are focused on finding those rates that provide disease control but do not have any phytotoxic effects. Application of ALS sooner in the season or in the fall is also being investigated as a way to avoid phtotoxicity to the crop. The use of ALS to control soilborne pathogens is under patent protection. Work is continuing toward developing ALS into a formulated product not only for managing soilborne diseases but for other agricultural uses as well.

Strawberries Respond to Soil Fumigation: Microbial Mechanisms and Some Alternatives to Methyl Bromide

J. M. Duniway, C. L. Xiao, and W. D. Gubler, Department of Plant Pathology, University of California, Davis, CA 95616

The experiments reported here are part of a larger project supported by the California Strawberry Commission and ARS–USDA to research chemical and nonchemical alternatives to methyl bromide for preplant fumigation of soil in strawberry production. We tested chemical alternatives to methyl bromide in replicated field experiments at a coastal site near Watsonville, CA.

Strawberries were grown every year for four years (1994–98). *Verticillium dahliae* was present in the soil and bed fumigation treatments were applied in early October of each year. Two-row beds were shaped, fumigated (two

shanks/bed, 15–20 cm deep, rates given per unit of treated bed area which was 58 percent of the total area), and covered with black plastic mulch. One month later, we transplanted Selva through the plastic mulch and followed conventional practices for annual strawberry production and pest management for the area. This included using sprinkler irrigation initially and drip irrigation in the production season. We picked berries for fresh market at least weekly for several months using normal grower practice.

All of the bed fumigation treatments used in 4 years of experiments increased yield significantly, compared to nonfumigated soil. For example, yields in 1997 and 1998, respectively, relative to those obtained following standard bed fumigation with methyl bromide/chloropicrin (67/33 percent @ 325 lb/acre), were 117 and 76 percent for chloropicrin alone (300 lb/acre), 105 and 87 percent for Telone/chloropicrin (65/35 percent @ 425 lb/acre), or 66 and 45 percent for nontreated soil. Application of the Telone/chloropicrin mixture to beds at the same rate in a water emulsion through drip lines gave yields of 102 and 104 percent relative to those obtained on beds fumigated with methyl bromide/chloropicrin, while broadcast fumigation with methyl bromide/chloropicrin (67/33 percent, 315–330 lb/acre total area) gave relative yields of 112 and 96 percent. All fumigation treatments reduced *V. dahliae* populations in soil and effectively controlled weed growth through plant holes in the plastic mulch.

The results show that bed fumigations with the materials used can be effective and that drip application of emulsified Telone/chloropicrin shows promise, but the specific methods of application need further research. The use of a virtually impermeable plastic mulch (Bromotec Y681B, Lawson Mardon Packaging, U.K.) in 1998 improved yields on average by 16 percent over those obtained with a standard black polyethylene mulch in the bed fumigation treatments above, with chloropicrin or Telone/chloropicrin applied at rates reduced by one third.

Four experiments on a broccoli-strawberry rotation on nonfumigated soils have been completed. At Davis, CA, where *V. dahliae* is absent, one year of fallow or one year of broccoli production did not increase subsequent strawberry yields over those obtained with continuous strawberry production. Fumigation with methyl bromide/chloropicrin in the same experiment increased strawberry yields 54 to 69 percent. At the Watsonville site with high populations of *V. dahliae* present, a one-year rotation with broccoli increased subsequent strawberry yields by 24 to 38 percent. One year of rye increased yield 18 to 44 percent, relative to continuous strawberry, all on nonfumigated soil. Yield increases following one-year rotations out of strawberry, however, were approximately half as large as those obtained by soil fumigation in the same site and years. Although current California strawberry varieties are all susceptible to Verticillium wilt, the relationship of disease incidence to initial populations of *V. dahliae* in soil differed significantly between the varieties Selva and Camarosa.

We are researching microbiological differences associated with the enhanced growth and productivity of strawberries in soils fumigated with methyl bromide/chloropicrin where the response is not due to control of known, major pathogens. Plants in fumigated soils consistently had higher root length densities and fewer dark roots than plants in nonfumigated soils. Relative to nonfumigated soils, total numbers of fungi are usually low for several months following fumigation. *Cylindrocarpon* spp. were isolated from 0.5-cm segments of strawberry roots grown in nonfumigated soils (mean frequency 14 percent) but not from roots grown in fumigated soils. *Pythium* spp. were more commonly isolated from roots in nonfumigated soils, with mean isolation frequencies of 3 and 11 percent for fumigated and nonfumigated soils, respectively. *Rhizoctonia* spp. were frequently isolated from roots in both fumigated and nonfumigated soils.

Pathogenicity of the predominant isolates of these fungi was tested on strawberry in the greenhouse. *Cylindrocarpon* spp. did not cause significant root rot, but some isolates caused significant reductions in shoot and root growth. *P. ultimum* caused root rot and growth reductions. Of the 14 binucleate isolates of *Rhizoctonia* spp. tested, four caused significant root rot and growth reductions, while three others caused only growth reductions.

Total populations of bacteria in soil were not affected by fumigation, but fluorescent Pseudomonads were significantly less 5 days after fumigation. Populations of fluorescent Pseudomonads in soil, however, increased quickly following fumigation and were 10 to 1000 fold higher than in nonfumigated soils 10 days to 9 months after fumigation. Predominant isolates of fluorescent Pseudomonads from the rhizosphere were tested for

effects on strawberry growth in natural field soil in the greenhouse. The effects of individual isolates ranged from beneficial (increased shoot and root dry weights up to 72 percent and 162 percent, respectively) to deleterious (about 20 percent shoot or root reduction).

Pseudomonas fluorescens, *P. putida* and *P. chlororaphis* were among the most predominant and beneficial rhizobacteria tested. The results suggest that reductions in deleterious fungi and increases in beneficial fluorescent Pseudomonads contribute to the enhanced growth response of strawberry to soil fumigation with methyl bromide/chloropicrin.